FORAGE PRODUCTION

Harvesting Winter Forages to Extract Manure Soil Nutrients

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ABSTRACT

Harvested hay captures soil manure nutrients, which, if not utilized, could cause pollution of surface water or aquifer. This study determined yields of hay and N, P, K, Mg, Mn, Ca, Fe, Zn, and Cu of three winter forages for five harvest systems. Dormant bermudagrass [*Cynodon dactylon* (L.) Pers.] sod fertilized with swine (*Sus scrofa domesticus*) effluent was fall seeded with 'Kenland' red clover (*Trifolium pratense* L.), 'Bigbee' berseem clover (*T. alexandrinum* L.), or 'Marshall' annual ryegrass (*Lolium multiflorum* Lam.). Forage was removed for three springs with single 1 June harvest or with one of four two-harvest-day systems: 1 April and 1 June, 15 April and 1 June, 1 May and 1 June, and 15 May and 1 June. Mean herbage yields were similar for the forages, but nutrient yields and best harvest date varied. Ryegrass yields across harvests were similar except for a reduced 1 May and 1 June harvest. 1 April and 1 June was usually the best harvest for the clovers while the single 1 June was the poorest. The use of two spring harvests for the legumes increased yields up to 130% of the single harvest. The legumes yielded up to 64% more N, 24% more P, and 40 and 72% more of the metals Zn and Cu than the ryegrass. The 1 April harvest of berseem clover removed >30 kg ha^{-1} yr^{-1} of soil P. Management of soil nutrients is critically affected by choice of winter forage and harvest system.

In the USA, concentrating animal production in relatively small areas has supported the economy of production but the quantity of animal waste produced has sometimes increased the risk of environmental pollution with manure nutrients, N and P (USEPA, 1996). In the absence of dramatic decreases in frequency of eutrophication events in ponds, lakes, and streams, state and federal agencies are expected to continue the development and implementation of regulation for management and use of animal manures. Critical to much of the regulation are the comprehensive nutrient management plans that address site specific issues in nutrient management to include timing and rates of land application of animal waste, cropping systems, tillage practices, soil types, and manure constituents (Sims et al., 2000). This plan links land application rates to crop utilization rates under the straightforward premise that if nutrients are extracted from the soil in the harvested crop, they will not contribute to pollution at that location (Sharpley et al., 2000; Chambers et al., 2000).

Control or management of soil nutrient concentrations is critical to reducing the potential for eutrophication (Withers and Jarvis, 1998; Chambers et al., 2000). Eutrophication events may persist because of regional soils and site specific environmental factors (Combs and Bundy, 1995) and because of P recycling from deposited lake sediments (Jacoby et al., 1982). The concentration of nutrients in soil is expected to change as a function of organic and inorganic nutrient inputs and nutrients extracted in harvested plant materials in the absence of surface erosion or percolation of these nutrients through the soil profile (Klausner, 1995). It is now recognized that N may be lost anywhere in a watershed (Gbubrek et al., 2000; Chambers et al., 2000).

A critical element of the nutrient management plan is the forage crop to which the animal manure is applied and the management of that crop. To avoid adversely affecting the environment, manure nutrients must be applied to soil at rates utilized by plants. A recognized best management practice in the South is the use of the winter cover crops for control of soil surface erosion, but recent research by Brink et al. (2001) indicated the added benefit of harvesting the cover crop is to extract 10 to 25% more P than would be harvested just in the summer. With a single spring harvest, the ryegrass removed as much or more P as the three grains and 12 legumes fertilized with poultry litter.

The forage farmer concerned with feed value of his forages has long known the importance of the frequency and timing of spring harvests. Usually, under cool conditions, nutrient concentrations decrease as the crop matures, but hay yield often increases with delay in harvest. For hay operations, choice of harvesting date is commonly a compromise between decreasing protein content, decreasing digestibility, and increasing herbage yield. The most common winter cover crop in the Mid-South is annual ryegrass because it is inexpensive and adaptable (Brink et al., 2001) and hay has been proposed for remediation or control of soil nutrient concentrations (Brink and Rowe, 1999). Hay drying in the South may be difficult in the spring because of the rains, but haylage may be a reasonable alternative. It may be necessary to harvest spring hay without regard to economic use, just to sustain land applications of animal waste. The objectives of this research were to determine how choice of forage species and cutting dates in spring harvested forage can effect more rapid extraction of manure nutrients from the land fertilized with swine effluent. This data supports the further development of more accurate nutrient management plans.

MATERIALS AND METHODS

This 3-yr study was conducted at a commercial swine farm near Pheba, MS (33°35′ N, 88°56′ W) on a Prentiss loam (coarse-loamy, siliceous, semiactive, thermic Glossic Fragiu-

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Published in Agron. J. 95:1209–1212 (2003).

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dults). In the previous 3 yr, the producer established a common bermudagrass sod and fertilized the area using a center pivot irrigation, which pumped swine effluent from a single-stage anaerobic lagoon. During the summer, the field was regularly irrigated in 1-cm increments (because of puddling concerns) with a total of about 15 cm of effluent applied each summer, which had nominal nutrient concentrations of 300 to 420 mg N L^{-1} and about 60 mg P L^{-1}. The annual fertilization rates were 520 kg N ha^{-1} and 110 kg P ha^{-1}. In the effluent, the N is approximately 84% NH_4–NH_3 and the P is 80% water soluble ortho-P (Adeli and Varco, 2001).

Beginning in fall 1997, plots (2 by 4 m) of dormant bermudagrass sod were planted with either 'Kenland' red clover at 16.8 kg ha^{-1}, or 'Bigbee' berseem clover at 16.8 kg ha^{-1}, or 'Marshall' annual ryegrass at 44.8 kg ha^{-1} using a Tye drill on about 1 October. The forages were harvested either as a single June harvest or one of four two-harvest-date systems: 1 April and 1 June, 15 April and 1 June, 1 May and 1 June, and 15 May and 1 June. (To simplify discussion and presentation, these harvesting options are hereafter named by the date of the first harvest, i.e., 1 April, 15 April, etc.) For each harvest, a 0.9-m swath through the center of each plot was cut at a 5-cm height with a sickle bar mower. The forage was weighed and subsampled for determination of moisture and nutrient concentrations. Berseem clover and ryegrass are winter annuals and the red clover performed as an annual under this management.

The factorial arrangement of treatments consisted of the five harvesting regimes and the three winter forages replicated four times in a split-block design with harvesting system as the whole plot. Each year a new randomization of the treatments was applied to the plots. Subsamples of the forage harvests were dried at 65°C for 48 h, ground to pass through a 1-mm screen, and then sealed in plastic containers. Nitrogen content of forage was determined with duplicate samples using an automated dry-combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). The concentrations of P, K, Ca, Cu, Fe, Mg, Mn, and Zn were estimated on duplicate subsamples with the following procedure of Brink et al. (2001): duplicate 1-g subsamples were ashed at 500°C for 4 h, and then 1.0 mL of hydrochloric acid (aqueous HCl) and purified water was added to the crucible. This was filtered after 1 h in the double acid solution (83 mL HCl and 14 mL H_2SO_4 brought to 20 L with purified water). The eight nutrients were measured by emission spectroscopy on an inductively coupled, dual axial Argon plasma spectrophotometer (Thermo Jarrell Ash Model 1000 ICAP, Franklin, MA).

Forage yields are reported on a dry weight per hectare basis for the total spring harvest. Nutrient extraction was estimated as the product of nutrient concentration in the hay and hay yield for each plot at each harvest. Statistical analysis was executed with SAS procedures (SAS Inst., 1989) on a data set that was balanced and complete. Appropriate error terms were used to test for significant effects reflecting the randomization restrictions of the split-plot design (Hinkelmann and Kempthorne, 1994) and most interactions with blocks were pooled into the error term. Means separations were estimated for fixed effects using Fisher LSD with $\alpha = 0.05$ criteria.

RESULTS AND DISCUSSION

Weather for the three springs was variable but typical for the location. The spring of 1999 was cooler later in the year than the other years and is postulated to be a cause for the lower hay yield. The mean hay yields for the years 1998, 1999, and 2000 were 9.80, 6.87, and 8.54 Mg ha^{-1}, respectively. Differences among years for all traits were always highly significant (Table 1) and most of the interactions with years were statistically significant. The average annual hay yields of berseem clover, red clover, and annual ryegrass (8.62, 8.24, and 8.34 Mg ha^{-1}, respectively) were nearly identical. The average hay yield for harvest dates were significantly different ($P < 0.01$) and ranking from the largest are 1 April, 9.05 Mg ha^{-1} (A); 1 June, 8.51 Mg ha^{-1} (AB); 15 May, 8.37 Mg ha^{-1} (BC); 15 April, 8.16 Mg ha^{-1} (BC); and 1 May, 7.91 Mg ha^{-1} (C) (weights followed by the same upper case letter in brackets are not significantly different using Fisher LSD, $\alpha = 0.05$).

Many of the interactions for the treatment variables were statistically significant (Table 1). For hay yield and macro nutrients, N, P, K, and Mg, the interactions with forage species were always statistically significant. With the many significant interactions, conclusions about treatment effects must be developed with care.

The significant interaction of forage species and year indicates that the best nutrient extraction or hay yield changed among species each year or that the difference between any two species changed from 1 yr to the next. This common interpretation of the results is a postdictive explanation and describes what did happen in this experiment (Gauch, 1992). But from a practical viewpoint, the random variability across years is normal and expected. Thus, when treatment effects are statistically significant and the differences in levels of a treatment have a magnitude that is of biological consequence in the presence of interactions with random factors, the research conclusions have generality. The ultimate objective is to predict the response over years complete with the perturbations due to seasonal and annual ef-

Table 1. Tests for significant statistical effects on hay yield and nutrient yield with three forages harvested with five protocols over 3 yr.

	Measured yield									
Effect	**Hay**	**N**	**P**	**K**	**Mg**	**Mn**	**Ca**	**Fe**	**Zn**	**Cu**
Block										
Year	**	**	**	**	**	**	**	**	**	**
Harvest	**	**	**	*	*	*	ns	*	ns	ns
Harvest × Year	**	**	**	**	**	**	**	*	*	ns
Year × Harvest × Block	ns	ns	ns	ns	ns	ns	ns	*	**	*
Forage	ns	*	**	**	*	ns	**	**	**	**
Year × Forage	**	**	**	**	**	**	**	**	**	**
Harvest × Forage	**	*	*	*	*	**	ns	**	ns	ns
Year × Forage × Harvest	**	**	*	**	**	ns	**	ns	ns	**

*** Statistical significance of effect at $\alpha = 0.05$.**
**** Statistical significance of effect at $\alpha = 0.01$.**

fects. Thus confidence in the means of treatment combinations or main effects rests on sampling an array of environments representative of the reference area. To elucidate trends and investigate interactions among the fixed effects, the means for the factorial arrangement of treatments, three forage species by five harvest dates, are presented with LSD tests on significant differences among the means (Table 2).

Though the average hay yield of the three forages was nearly identical, they responded differently to harvest system. The best hay yield for the two clovers was the 1 April harvest but the single 1 June harvest was best for the ryegrass. The poorest hay yield harvest was 1 May for both berseem clover and ryegrass and 1 June harvest had the lowest hay yield for the red clover. Thus, responses to earlier cuttings and greater or less time for regrowth does not simply result in monotonic increase or decrease in hay yield. Because of the unexpected poor 1 May yield, a detailed inspection was made of the hay yield data for the treatments within each block and in each year. These measurements were not found to be more variable than for any other harvest date for ryegrass and berseem clover.

If the concentrations of any nutrient were unaffected by harvesting system or other factors, the nutrient extractions for each forage would parallel the hay yields shown in the first three columns of Table 2, but this was not the case. The lowest N yielding harvest was 1 June for all forages, even though ryegrass had its largest hay yield with the 1 June harvest. As expected with the legumes, the N concentrations were higher and with equal hay yields the legume hay averaged about 50% more N than the grass hay (197 and 186 vs. 120 kg ha^{-1}). The harvest date for each forage had a significant effect on N extraction. The 1 April harvest of berseem clover extracted 37% more N than that of the June 1 harvest (224 vs. 163 kg ha^{-1}) and the 1 May harvest of the red clover extracted 46% more N than the single 1 June harvest (217 vs. 149 kg ha^{-1}). Though the ryegrass contained much less N, the choice of harvest date was again critical. The 15 April harvest of ryegrass had 29% greater N than the single 1 June harvest (137 vs. 106 kg ha^{-1}). The higher N content of the legume may be attributed to N fixation, but this difference in nutrient contents of legume and grass is also found for other elements.

Choice of harvest date was critical to rate of P extraction only for the legumes. The P extraction was not significantly different for the ryegrass harvest dates, even though the hay yields varied greatly. For the clovers, harvesting berseem clover on 1 April instead of 1 June extracted 36% more P (30.2 vs. 22.2 kg ha^{-1}) and the 1 May harvest of the red clover extracted 38% more P than the 1 June harvest (27 vs. 19.6 kg ha^{-1}). Earlier research by Brink et al. (2001) reported ryegrass superiority or near equality for P removal in comparison to 11 legumes including red clover and berseem clover. The difference in conclusions may be because the nutrient availability of swine effluent approaches that of commercial inorganic fertilizers (Adeli and Varco, 2001).

The physiological responses to harvest date were unexpected. For ryegrass the harvest date had a significant effect for 8 of the 10 measurements. For these eight, six of them (hay yield, K, Mg, Ca, Fe, and Zn) followed

Table 2. Yield of hay and nutrients with five harvest systems on berseem clover (BC), red clover (RC), and annual rye grass (RG).

First harvest date	Hay yield			N			P			K		
	BC	RC	RG	BC	RC	RG	BC	RC	RG	BC	RC	RG
	Mg ha^{-1}			kg ha^{-1}								
1 April	9.24 A†	8.90 A	9.02 A	224 A	182 B	123 AB	30.2 A	23.6 B	23.0 A	306 A	259 AB	194 A
15 April	8.46 AB	7.90 AB	8.13 B	214 A	187 AB	137 A	29.5 A	24.2 AB	23.3 A	302 A	255 AB	183 AB
1 May	8.03 B	8.71 AB	6.98 C	203 AB	217 A	118 AB	27.8 AB	27.0 A	21.1 A	289 A	290 A	170 B
15 May	8.93 AB	7.99 AB	8.19 B	181 BC	192 AB	114 AB	25.7 BC	23.5 B	21.0 A	274 A	257 AB	181 AB
1 June	8.44 AB	7.69 B	9.40 A	163 C	149 C	106 B	22.2 C	19.6 C	20.9 A	232 B	219 B	179 AB
Mean	8.62 a‡	8.24 a	8.35 a	197 a	186 a	120 b	27.1 a	23.6 b	21.9 c	281 a	256 b	181 c

Harvest date	Mg			Mn			Ca			Fe		
	BC	RC	RG	BC	RC	RG	BC	RC	RG	BC	RC	RG
	kg ha^{-1}			g ha^{-1}			kg ha^{-1}			g ha^{-1}		
1 April	18.6 A	16.2 AB	11.0 A	738 A	782 A	696 A	76.9 A	55.4 A	26.4 A	785 A	532 A	445 A
15 April	19.0 A	16.3 AB	10.9 A	821 A	726 A	743 A	78.6 A	55.6 A	25.4 AB	613 B	520 AB	415 AB
1 May	18.3 A	19.1 A	9.4 B	689 AB	730 A	573 B	76.2 A	59.8 A	22.0 B	577 B	610 A	356 B
15 May	17.1 A	17.2 AB	10.5 AB	581 B	660 A	790 A	83.4 A	57.3 A	25.6 AB	538 B	494 AB	418 AB
1 June	13.7 B	15.2 B	10.7 A	560 B	716 A	780 A	73.4 A	57.5 A	26.7 A	482 B	456 B	394 AB
Mean	17.4 a	16.8 a	10.5 b	678 a	723 a	716 a	77.8 a	57.1 b	25.2 c	600 a	522 b	406 c

Harvest date	Zn			Cu		
	BC	RC	RG	BC	RC	RG
	g ha^{-1}					
1 April	229 AB	187 AB	177 A	61.8 A	59.8 A	35.3 A
15 April	259 A	210 A	176 A	60.0 A	55.5 AB	37.4 A
1 May	224 AB	199 A	139 B	61.0 A	57.8 A	33.4 A
15 May	230 AB	186 AB	159 AB	55.1 A	52.4 AB	33.7 A
1 June	210 B	166 B	171 A	56.5 A	47.3 B	31.2 A
Mean	230 a	190 b	164 c	58.9 a	54.4 b	34.2 c

† In a column, means followed by the same upper case letter are not significantly different by LSD with $\alpha = 0.05$.

‡ For each three mean measurement in this row followed by the same lower case letter, the means are not significantly different by LSD with $\alpha = 0.05$.

the same trend in hay yield or nutrient extraction across harvest days so that 1 April > 15 April > 1 May < 15 May < 1 June. Obviously this is a mix of double and single harvests, but the symmetry is interesting because it does not simply relate to the length of time between first and last harvest. For the berseem clover the differences among harvests were significant for 9 of the 10 measurements. For N, P, K, and Fe the extraction decreased for later harvests: 1 April > 15 April > 1 May > 15 May > 1 June.

For all elements except Mn, the ryegrass extracted less of each nutrient than did the legumes. The Ca extraction was little affected by harvest date, but red clover and berseem clover crops had 100 and 200% more Ca, respectively, than the ryegrass. Clovers had 70% greater extraction of Mg and berseem clover and red clover extracted 29 and 48%, respectively, more Fe than did the ryegrass. A secondary effect of the differences in nutrient extraction that impacts economic value is that the ryegrass is expected to have less nutrient value than either of the legumes when harvesting date is optimized.

The heavy metals of environmental concern, Zn and Cu, are extracted much more rapidly by red and berseem clovers than by the ryegrass. The berseem clover extracted, on average, 70% more Cu and 40% more Zn than the ryegrass. Thus, if Zn or Cu pollution were a concern, management does have the option to use the berseem clover to control concentrations of these soil nutrients. This difference in uptake of Zn and Cu for legume and grass was reported by Brink et al. (2001) for fields fertilized with poultry litter. In contrast to the large differences among species, the harvesting date had little or no impact on extraction of Zn or Cu (Table 2).

CONCLUSIONS

Farmers need information on all possible agronomic options to protect the environment and to ensure their continued economic existence. In the South, the winter cover crop is recognized as an effective tool for protecting soil surface from erosion and reducing the potential of particulate P loss. The cover crop captures nutrients such as N, which might otherwise leach from the soil in the many winter rains. This research shows that harvesting the winter cover of ryegrass, berseem clover, or red clover can reduce nutrient accumulations in soil exposed to continued manure fertilization. For fields fertilized with swine effluent, the choice of forage species and the harvesting date were critical to rate of nutrient extraction. The best species was usually the berseem clover, but best harvest system sometimes varied for the nutrients and certainly varied among the forage species. For the two harvest date systems, the longer or shorter times between the first harvest and the final 1 June harvest was not simply related to an increase or decrease in hay yield or quantity of nutrient extracted. For clovers, all of the two-harvest-day systems were better than the single 1 June harvest. For ryegrass, a single harvest may be as effective as any of the two harvest systems. Though legume seed is more expensive than the ryegrass and establishment may be more demanding, the removal of 25% more P, 40% more Zn, and 72% more Cu, along with production of a more valuable hay, may be compelling reasons to utilize the clover as a winter cover crop.

ACKNOWLEDGMENTS

The authors express their appreciation to Ms. Quinnia Yates for her significant technical support.

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